THE GEOLOGY AND PETROLOGY OF THE GREAT SERPENTINE-BELT OF NEW SOUTH WALES.

Part iv. The Dolerites, Spilites, and Keratophyres of the Nundle District.

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(Plates xxv.-xxvii., and six text-figs.)

Introduction.—The first three Parts of this series recently issued(1) contain some of the results of field-observations made during the years 1909-1911, and of petrological observations made in Cambridge, whither the writer proceeded, having been awarded a Research Scholarship, by the Royal Commissioners of the Exhibition of 1851. Attention was devoted in the field chiefly to the occurrence of serpentine, and the intricate relationships of the dolerites and spilites were less studied, for the peculiar interest attaching to them was then unknown. A perusal of Messrs. Dewey and Flett's paper on British Pillow Lavas(2) showed the importance of these rocks, but the material that had been collected was not sufficient to allow of a detailed discussion, and a re-examination of the field-evidence was necessary. The following is the result of six weeks' further work in the Nundle district, and the study of about one hundred and seventy thin slices of the rocks collected.

In the previous papers it was recognised that the coarse-grained dolerites were intrusive sill-like bodies, and it was believed that the fine-grained, or aphanitic, and frequently amygdaloidal spilitic rocks were lava-flows. At the same time it was remarked that many passage-rocks existed, and that it was frequently found difficult to refer an amygdaloidal dolerite of medium grainsize either to the one group or to the other. The same doubt as to the distinction of flow from sill has arisen in most localities in which these rocks occur. A second difficulty exists in the nomenclature. It was pointed out that the term "spilite" by original definition and present-day usage covered only such rocks as had undergone a considerable amount of alteration, with the formation of abundant secondary minerals. This has not always been the case among our rocks in New South Wales, unless we are to consider the acid felspar as a secondary mineral (a point which is discussed below), though in all essential features, chemical composition, structural characteristics, and geological association, they agree entirely with the rocks to which Dr. Flett has applied the term "spilite." To indicate this similarity in essential features, it seemed best to extend the use of the term to cover the apparently unaltered rocks in New South Wales, and the name "spilite" will be employed in the sequel in the same sense as before. The distinction adopted to separate the dolerites and spilites, is one of texture and grainsize: the former have a coarse or medium grainsize, with an ophitic, granular, or intersertal texture; the latter are fine-grained, or partially glassy, with a more or less variolitic texture. All gradations may be found between them. Mineralogically, they differ from normal dolerites and basalts chiefly in the strongly sodic nature of their felspars.

Geological Occurrence.—The general sequence of sedimentation in the Nundle district has been already discussed in Part ii. of this series. Briefly, the Devonian formation consists of a lower portion, the Woolomin Series, comprising phyllites, tuffs, and radiolarian jasper; a middle portion, the Bowling Alley or Tamworth Series, consisting of radiolarian cherts and claystones, volcanic tuffs and breccias, and coral limestones; and an upper portion, the Nundle or Barraba Series, made up of mudstones, containing *Lepidodendron australe* and radiolaria, with numerous bands of tuff and breccia. Spilites and dolerites occur in some amount in the Woolomin Series, are abundant in the Bowling Alley Series, but are absent from the Nundle Series In Carboniferous times, the formation was strongly folded, and slightly overturned towards the west, and a great mass of peridotite was injected into the plane separating the Woolomin Series from the main bulk of the Bowling Alley Series. A large amount of strike-faulting took place, which has greatly disturbed the stratigraphical succession, and this revision of the area makes it appear probable that some modification will have to be made in the detailed succession previously announced. It is hoped to discuss this in a later communication, after comparative work has been done in less complex areas. The consideration of the tuffs and breccias (which, doubtless, are cognate with the dolerites and spilites) is also reserved for future study.

Detailed examination of the lines of contact between the igneous and sedimentary rocks, shows that the extent of true lava-flows has been overestimated. In nearly every instance, the igneous rock is intrusive into the sedimentary rock, whether it be a coarse-grained dolerite or a fine-grained spilite: indeed, there has only one instance been observed where doubt can exist on this point. An interesting fact brought to light in this revision, is the frequent occurrence of the pillow or ellipsoidal structure, which is so common a feature of British and German spilite-lavas. But, though it has been held by some writers that this structure is characteristic of lavas that have flowed over the surface of the sea-bottom, it does not appear to be confined to these. Pillow-structure is well developed in the Nundle district in rocks which show intrusive contacts with the surrounding sediments (radiolarian claystones), and the alternative view held by other writers, *e.g.*, Teall(**3**) and Geikie(**4**)* that pillow-structure may also be produced in lavas intrusive into loosely compacted clays on the sea-floor, is the one most applicable to the features seen in the Nundle district. The various explanations that have been offered for the explanation of pillow-structure have been discussed by Clements(**5**), Daly(**6**), Sundius(**7**), Van Hise and Leith(**37**), whose papers give extensive bibliographies of the subject.† Tempest Anderson describes the formation of pillow-structure in recent

* "Basic lavas flowing into water or watery silt."

† Since the above was written, Wilson's discussion of the origin of pillow-structure in the Archæan rocks of North-western Ontario has come to hand (The Geology of the Kewagama Lake Map-Area, Quebec. Geol. Survey of Canada. Memoir 39, p.50). He cites, though he disputes, Lawson's statement that the ellipsoidal rocks of California are intrusive (Mining and Scientific Press, No.119, Vol. iv., 1912, p.199).

lavas in Savaii as follows(8): —"An ovoid mass of lava still in communication with the source of supply, and having its surface, though still red-hot, reduced to a pasty condition, would be seen to swell or crack into a sort of bud with a narrow neck like a prickly pear on a cactus, and this would rapidly increase in heat, mobility, and size, till it either became a lobe as large as a sack or pillow, like the others, or perhaps stopped short at the size of an Indian club or large Florence flask. Sometimes the neck supplying the new lobe would be several feet long and as thick as a man's arm before it would expand into a full-sized lobe; more commonly it would be short, so that the fresh-formed lobes were heaped together." Sundius accepts this as the process by which the pillow-lavas were made in the pre-Cambrian rocks of Lappland, but suggests that the pressure of the moving lava may break off and separate the pillows from one another : this would account for the rarity of connecting tubes between the pillows in the lavas he describes. Daly, in his recent work(9), compares the production of these lava-ellipsoids to the formation of the "spheroidal state" in water. Sundius notes that the effect must depend on the possession by the magma of a definite degree of viscosity, and finds in this the explanation of the association of pillowy and non-pillowy lavas. Mr. Harker has pointed out(10) that there is only a slight difference between the conditions of injection of lava into the loose muds of sea-floor, and an outflow of lava over the sea-floor, which is but the injection of magma between the soft muds and the overlying water.* The difference is naturally to be found in the slower cooling of the lava in the former case owing to the blanketing action of the muds. It seems quite probable that a flow with typically pillowy surface may show an intrusive contact with the mud-surface on which it rests, and such may be the case in parts of the Nundle district. While, in many instances, pillow-structure is a feature of deep-sea marine flows, as is shown by the fine-grained nature of the sediments with which they are associated, it is clear, from Tempest Anderson's observations, that it cannot be confined to such situa-

* Compare F. von Wolff. Der Vulkanismus (Stuttgart, 1913), pp.252 and 255.

tions; and, moreover, pillow-lavas have been found associated with lacustrine deposits(**36**). Jukes-Brown has argued for the shallow-water origin of the radiolarian rocks associated with the pillow-lavas of Ballantrae in Ayrshire(**11**), and Professor David and Mr. Pittman have declared that the Tamworth radiolarian claystones etc., which are continuous with those associated with the pillow-lavas of the Nundle district, were developed in comparatively shallow water(**12**).

The mode of occurrence of special masses may now be described. No doubt can exist as to the intrusive character of any of the large patches of dolerite marked on the geological map of the district given in Part ii. They all represent areas of dolerite of coarse or medium grainsize, and almost free from vesicles. Not infrequently there occur in them veins of very coarse-grained dolerite-pegmatite. Their intrusive contacts with the surrounding sediments are clearly observable. Often they have themselves been invaded by later masses of dolerite, which have a strongly marked, fine-grained, chilled, marginal zone against the invaded rock. Such contact-zones may be seen in several places in the lower part of Munro's Creek.

The areas marked as spilite-flows require more detailed consideration. The most important is that crossing the Peel River two miles south of Bowling Alley Point, and extending thence towards Hanging Rock. In the cutting on the main road, it consists of a group of stratiform masses, which may be seen to have intrusive contacts with the radiolarian claystones on either side. The same features are to be seen where this zone crosses Madden's, Moonlight, and Daylight Creeks, south of this point. The individual sills have a medium to fine grainsize, and are often amygdaloidal. In microscopical texture, they vary between ophitic dolerites and variolitic spilites: this variation may be seen on either side of a sill, and is due to marginal cooling; frequently, however, the sill is of uniform texture throughout. Multiple sills occur here and there, with chilled edges between the component parts. The vesicles are filled with calcite, epidote, and chlorite, and along the northern slope of Tom Tiger, axinite is frequently present in the vesicles, while axinite- and quartz-veins occur in the vicinity. Owing to the abundance of porphyry dykes in the vicinity, it was thought probable that the boric acid may have been derived from an underlying mass of granite which approached the surface in this region, though none of the porphyries contain tourmaline. There is, however, the possibility that the axinite may proceed from the dolerite-magma itself: axinitic contact-rocks are occasionally observed about diabases in Germany and New Jersey(**13**).

On Tom Tiger, the prominent peak north of the junction of Swamp Creek and the Peel River, pillow-structure is to be seen in the crags about the summit. The pillows are sometimes more than a yard in diameter, and their marginal zones of chilling are narrow and not well marked. They are separated by narrow bands of epidote, calcite and quartz. No exposures of the contact-line between the sediments and the igneous rock can be seen on Tom Tiger itself, but in Swamp Creek, half a mile to the south, a strongly intrusive junction is exposed. The bared rocks in the creek-bottom show that a considerable thickness, about ten yards, of fairly coarse-grained spilite is full of irregular, twisted fragments of chert of all sizes. The whole appearance suggests that the igneous rock invaded partially consolidated sediments. Pillow-structure is also observable here. Following the zone further southwards, pillow-structure is again met with on the ridge separating Swamp Creek and Happy Valley, and from this was obtained the specimen of spilite, of which an analysis was given in Part iii. The map in Part ii. shows a break in the spilite-zone south of this point, but it has now been proved to extend uninterruptedly to beyond Oakenville Creek, and the contacts with the sedimentary rocks, wherever visible, show the intrusive nature of the igneous rock.

A thickness of over four hundred feet of pillow-lava is exposed in the bed of Happy Valley. The pillows vary from a few inches to over six feet in diameter; the inner portion is porphyritic, with a subvariolitic base; the outer and rapidly chilled portions are aphanitic, and have frequently a variolitic structure. Vesicles are not abundant, nor are they concentrically arranged; they tend to concentrate towards the centres of the pillows. The individual masses are separated, as usual, by narrow bands of epidote, etc., and quite large crystals of quartz or epidote may occur in the cuspate cavities between several pillows; no radiolarian chert has been observed in such a situation, though it occurs in this manner in several British localities. Occasionally, the pillow-lavas are invaded by massive non-pillowy dolerite, which sometimes has chilled marginal zones.

Pillow-structure may also be observed on the cuttings on the Hanging Rock road, though greatly obscured by spheroidal weathering. The spilites are here intersected by a dyke of hornblende-lamprophyre. The exposures on Oakenville Creek, just to the south of the road, are almost entirely covered with drift; one exposure, however, shows a most intimate mixture of spilite and chert. Fig. 1 was traced from a flat-ground surface of a

Text-fig. 1.—Spilite intrusive into radiolarian clay. (Nat. size).

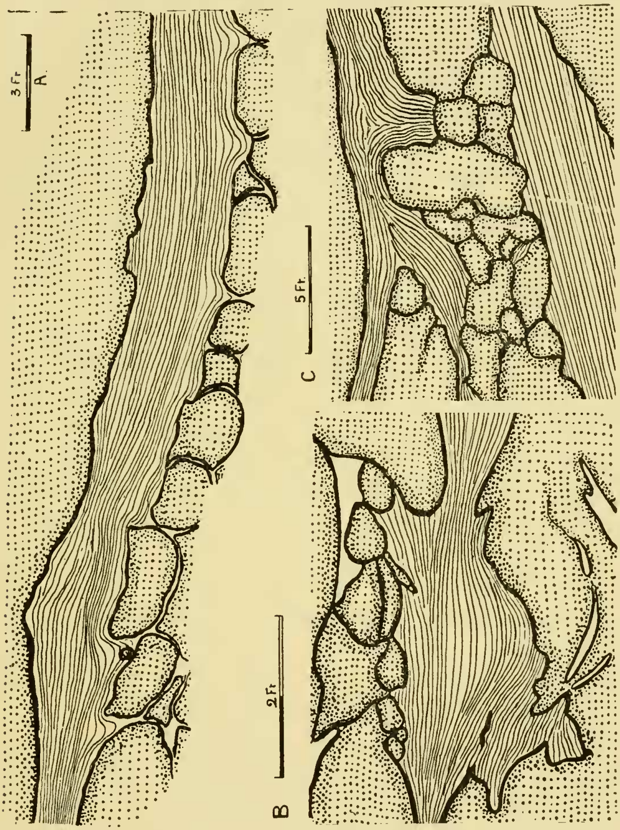
specimen obtained from here. The microscopical character of the entangled chert suggests that, in this case, it is largely, if not entirely, the product of infiltrations subsequent to the consolidation of the igneous rock. Such is believed by Messrs. Reynolds and Gardiner* to be the origin of the strings and patches of chert in the spilites of Kilbride Peninsula, County Mayo, Ireland.

Another important mass of pillowy rock commences nearly a mile further up Swamp Creek than the point where the first zone crossed, and continues thence up the gorge to the falls. It

* Quart. Journ. Geol. Soc., 1912, pp. 80-81.

may be a repetition of the first zone, though this does not seem probable at present. Near the entrance to the gorge is exposed the mass of chert and spilite shown in Fig.2A. This is the only instance in which doubt may exist as to the intrusive nature of the pillowy rock. The manner in which the banding in the chert bends in and out sympathetically with the boundaries of the lava-pillows, may indicate that they were deposited on a pillowy surface. On the other hand, the upper mass of lava has transgressive boundaries against the chert. It is not pillowy where it is in contact with the chert, but the structure becomes observable about thirty feet above the chert. The upper mass may be a surface-flow which has broken up the lines of bedding of the clays over which it flowed, but the section does not preclude the possibility that both the upper and lower masses of igneous rock were intrusive into soft clays, crumpling, or breaking through their lines of bedding as they went. Exposures of chert and spilite observed higher up the gorge clearly exemplify the second alternative. Indeed, there does not seem any other explanation possible for the features illustrated in Figs.2B and 2C. These narrow bands of chert lie in a great thickness of pillow-lava, probably four or five hundred feet (screes and tangling brushwood prevent more exact measurement). The pillows may be as much as eight feet in diameter, and are just like those occurring in Happy Valley. Not infrequently they are quite free from vesicles. In between the pillows is often a very fine-grained rock which looks like chert, but which the microscope proves to be made up of quartz, epidote and a little actinolite; the same minerals, less finely crystallised, form the usual bands separating the pillows. As in Happy Valley, there is no radiolarian chert between the pillows, nor do they show the strongly marked radial contraction-cracks that are sometimes seen in similar rocks in other parts of the world. There are associated massive intrusive dolerites quite indistinguishable, in hand-specimen, from the rock in the centre of the pillows (though under the microscope they may appear less variolitic), and it is often difficult to determine whether there is a passage from the pillowy rock into the massive dolerite, or whether there is a definite boundary between them.

No very definite statement is possible with regard to the other masses of spilite mapped, since their boundaries are rarely observable. It seems safest to consider them, also, as intrusive, whether they are vesicular or not, when there is no evidence to the contrary, and particularly when the rock is not pillowy, and



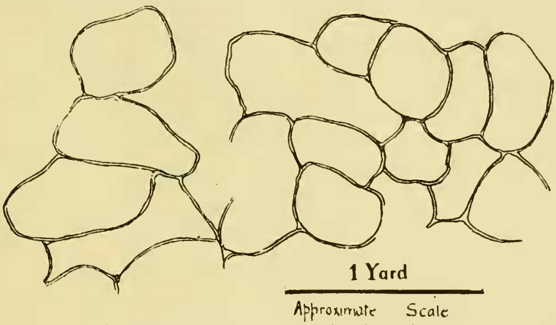
Text-fig.2.—Associations of chert and lava in Swamp Creek Gorge.

the texture is not more than subvariolitic. Even highly variolitic rocks have been proved to be intrusive. On such negative evidence, we may class as intrusive spilites or amygdaloidal dolerites, the bands shown on Moonlight Hill, those on the western side of Tom Tiger, and those forming the White Rocks overlooking Munro's Creek (see Part ii., Plate xxiii.). Confirmation of the intrusive nature of the first-mentioned group of spilites, is afforded by two poorly exposed contacts, and in the last case we find, on tracing the horizon of the igneous from the crags down across the scree-covered slopes into Munro's Creek, the great mass of White Rock is represented by a number of narrow sills, all intrusive into the cherts or claystones. But, though the sills often show transgressive boundaries, the general course of the mass is parallel to the strike of the country.

With regard to the statement made previously, that a lava-flow occurred on Moonlight Hill, swamping the coral-limestone, some modification must be made. A closer examination of the field-occurrence showed that the specimen described was not part of a flow, but of a mass of agglomerate, composed almost entirely of spilite-fragments, and evidently formed adjacent to the point of eruption. As stated, it contains large and small masses and fragments of limestone, some of which contain recognisable fossils of coral. On the western side of Munro's Creek, however, opposite to the Razorback, there is also an association of spilite and limestone, with somewhat analogous characters. The limestone, unfortunately, is so crystalline that no organic remains are preserved. It forms a lens about seventy yards long and ten wide. At its northern extremity, it is most intimately mixed up with lava showing skeleton-crystals and other indications of rapid chilling, and this passes laterally into a solid mass of lava, containing numerous fragments of limestones and calcite-filled vesicles. The igneous rock must here be an intrusive body, formed probably at a small depth below the sea-floor.

The nature of the spilite-occurrences in the Woolomin Series is not clear. Dolerites have been proved to occur, and a special type of spilite as yet not chemically analysed. They are rather crushed, and are less variable in texture than the igneous rocks in the Middle Devonian. Only one instance of pillow-structure (and that a dubious one) has been seen in the spilites of the Woolomin Series in the Nundle district; it occurs in a tributary of Munro's Creek. Generally the rocks are quite massive, and free from vesicles. It may be mentioned here that well marked pillow-structure has been observed in some amygdaloidal spilites occurring in the Woolomin Series in Portion 56, Parish of Loomberah, by the bridge over the Peel River, eleven miles south of Tamworth. These rocks are highly altered, as much so as the majority of the British spilites known to the writer. It cannot be doubted that long strips of Bowling Alley (Middle Devonian) rocks are faulted or folded in among the Woolomin Series, but the spilites of these strips should be usually distinguishable from those belonging to the Woolomin Series. Distinction between the two sets of dolerites is not clear at present.

Other rock-types occur that are cognate with the spilites, though differing from them in varying degree. In Munro's Creek, commencing at the Razorback, and running thence up to the end of



Text-fig.3.—Pavement of Pillow-Lava.

the westernmost branch of it, is a series of pale grey green rocks. This mass was overlooked in the first survey, being thought to have been merely a rather altered tuff. Its eastern side adjacent to the serpentine is a flow-breccia, and traces of the same rock appear on the western side of the mass on the other side of the creek. The main mass is composed partly of a very fine-grained variolite with a most peculiar microscopical structure, partly of a subvariolitic porphyritic rock, and partly of a rock with an almost doleritic texture, intrusive into the finely granular or aphanitic variolitic rock. The porphyritic rock has a well developed pillow-structure, and several pavements of it are exposed in the bed of the creek. Fig.3 illustrates one of these.

The doleritic type is abundant, but does not exhibit pillow-structure. It has not been possible to determine the mode of occurrence of these rocks. They lie in the most disturbed zone in the Bowling Alley rocks, and the steep scree-covered slopes on either side do not expose any lines of contact between the sediments and the igneous rocks. It is almost certain that the series is faulted and folded, probably in a syncline. The occurrence of the breccia on both sides of the creek may be due to this; lines of shearing are to be seen in the rock. It is not clear, also, whether any of the rocks were actual flows. At the southern extremity of the mass there is a band of variolite only a yard thick, lying in a rather wider band of decomposed flow-breccia. The line of contact between this and the sediments is indecisive. There is also no clear evidence as to the relation between the variolitic leucocratic rocks and the strongly magnetitic spilite, described above as intrusive into a limestone. There seems to be almost a passage between the two types. In the creek below, pillowy spilitic boulders are associated with the variolites, and here again passage-rocks seem to occur, but the relation of the two types *in situ* is unfortunately obscured. A passage from a rock free from magnetite into one rich in that mineral is not impossible, as will appear from the consideration of the magnetite-keratophyres. A dyke of odinite traverses the series.

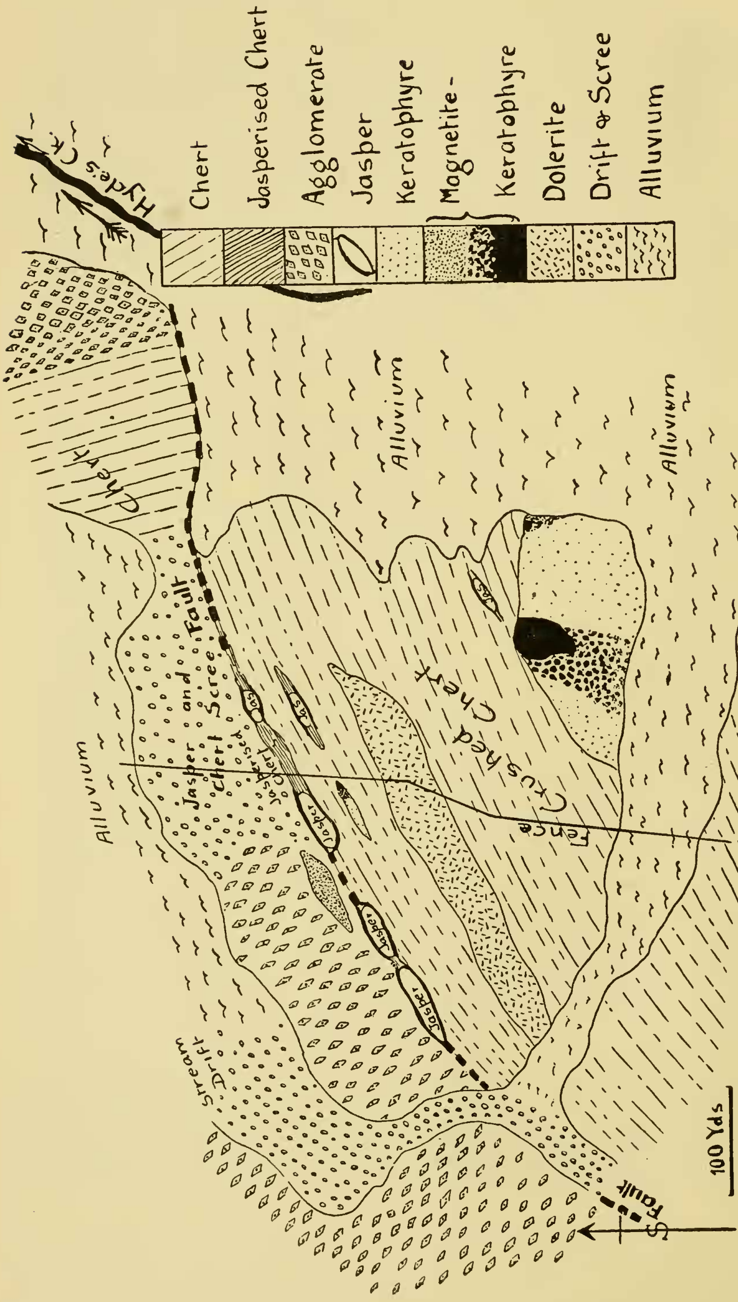
The most remarkable of all the rocks are the keratophyres. Of these are to be distinguished the keratophyres proper, the magnetite-keratophyres, the quartz-magnetite-keratophyres, and the quartz-keratophyres. The simplest occurrence is that of the keratophyre at Hanging Rock, which has been mentioned previously (Part ii., p.586; Part iii., p.666). It is also in a zone of great disturbance, and its relations are obscured. It seems preferable to consider it as a short sill, rather than as a volcanic plug. The rock is made up almost entirely of plagioclase, and analysis shows its extremely sodic character.

The magnetite-keratophyres are linked by passage-rocks both to the spilites and to the keratophyres. In the one sequence, the spilite passes into magnetite-keratophyre by the gradual diminution in the amount of augite present, and the increase in amount and decrease in grainsize of the magnetite; and by the substitution of a very slaggy for an amygdaloidal habit. The change from keratophyre into magnetite-keratophyre is a more complex one, and is discussed at length in the sequel.

North and south of Folly Creek, near the serpentine, there are small masses of spilitic magnetite-keratophyre, which seem to be intrusive into the adjacent sediments. No unusual tectonic features appear in their neighbourhood. Here and there throughout the district are little patches of spilite, richer than usual in magnetite, and showing some approach to the character of magnetite-keratophyres. These, however, are of rare and limited occurrence only.

The main region of development of the purely keratophyric type of rocks lies north-west of Bowling Alley Point in the region between Hyde's and Cope's Creeks. About a mile due west of the small infaulted area of Permo-Carboniferous rocks, is what may be termed the Hyde's Creek Complex. It forms a small ridge, running back from the creek. Fig.4 is a map of the occurrence. The normal strike of the region is that seen to the north-east of the figure, namely, N.N.W.-S.S.E. The strata following this strike are steeply inclined cherts and agglomerates or breccias. The strike warps round from N.N.W. to W.N.W. A fault cuts almost perpendicularly across this, and south of the fault lies an area, the strike of which swings from N.E. to E.N.E. The line of fault is marked by a series of masses of jasper, not of the usual red homogeneous character, but more clearly a secondary vein-like and vesicular rock, with quartz and chalcedony and crystalline hæmatite; the last is present as a finely divided colouring matter, as crystals in druses, and in veinlets through brecciated jasper. Where the jaspers cease, there continue zones of red jasperised radiolarian chert. Microscopical sections of these clearly show the metasomatic effect of ferruginous siliceous solutions.

Intrusions of igneous rock occur both north and south of the fault-line. At the southern end of the hillock is a complex of keratophyre and magnetite-keratophyre as shown. No actual contact with the chert has been seen, but the intrusive nature of

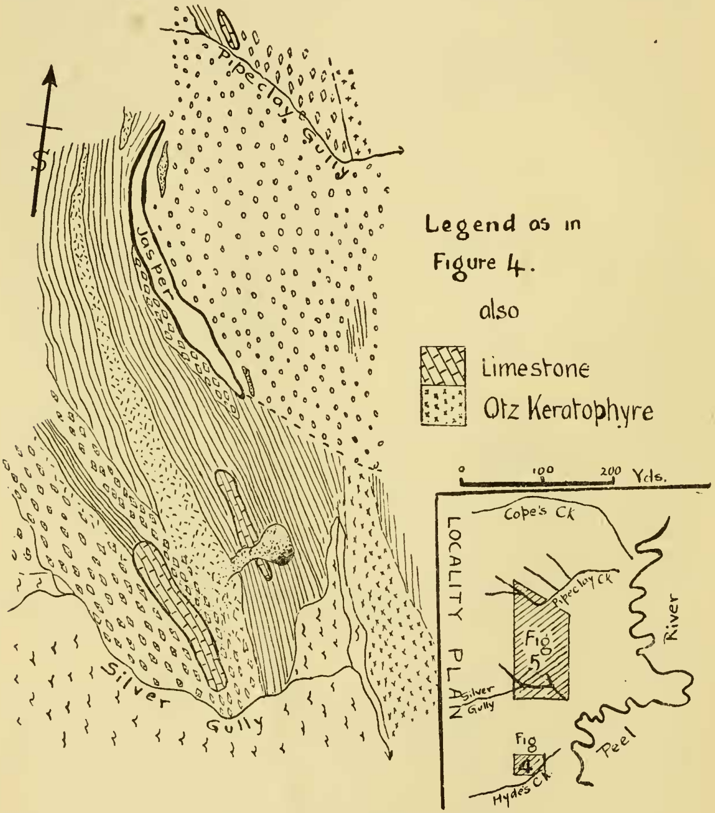


Text-fig. 4.—Hyde's Creek Complex.

the igneous rock can scarcely be doubted. The keratophyre, when fresh, has a translucent white colour, and is divided up into small portions, generally about two millimetres in diameter, closely compacted together, and generally without any intervening matrix. A little pyrites is usually present. On weathering, a white kaolinitic rock is produced, or a red or yellow ochreous one. Towards the centre of the mass, and also to the north-east, magnetite-keratophyre is developed. The passage from the one rock into the other is a gradual one through many peculiar intermediate types to be subsequently described. The increasing amount of magnetite may be regularly distributed, giving a uniform grey rock, but more usually it is very irregular, producing breccia-like or nodular rocks. Following these, are almost pure magnetite-keratophyres with but few veinlets of felspathic rock. Finally, in the centre of the ferruginous area, is a black, heavy, and very slaggy magnetite-keratophyre, in which the abundant irregular vesicles are never amygdaloidal, and are usually filled with calcite. A similar passage from purely felspathic into richly magnetitic rock occurs on the summit of the hillock. Between this and the former mass, is a long intrusion of quartz-dolerite, containing very little augite, and passing, on the margin, into fine-grained, non-porphyritic rock, the composition of which approaches that of an augitic quartz-keratophyre. North of the jasper-band, is a lenticular patch of very vesicular red-brown quartz-magnetite-keratophyre. The vesicles are round or slightly amygdaloidal, and the rock is not at all slaggy.

Along the zone of agglomerate to the north, other small occurrences of quartz-magnetite-keratophyre may be found, and the line of contact between these and the agglomerate is very difficult to define.

At Silver Gully, a mile north of the Hyde's Creek complex, is a second complex, of which a sketch-map is given (Fig.5). This is only very roughly drawn to scale. Beside the agglomerate, is a band of limestone forming a bold outcrop. To the east of this is a narrow band of spilitic agglomerate, beyond which is a long intrusion of dolerite like that in the Hyde's Creek complex. There does not seem to be a clear boundary between the agglomerate and the dolerite, and there is certainly no boundary between the dolerite and an offshoot of spilitic magnetite-keratophyre, which cuts across a second band of limestone, and opens out into a roughly circular area of fine-grained, red-brown and highly



Text-fig.5.—Silver Gully Complex.

vesicular (not slaggy), not very ferruginous magnetite-keratophyre, which passes into a richly magnetitic slaggy rock. The dolerite-sill may be traced for about half a mile to the north, and the agglomerate at its western edge seems to grade into a coarsely granular porphyritic quartz-keratophyre, which, on microscopic examination, proves to be composed entirely of fragmental quartz and albite. Agglomeratic rocks of a rather different nature, composed of fragments of keratophyre, magnetite-keratophyre, and dolerite in a matrix of keratophyre, lie to the west of a great band of jasper, which forms the ridge of the hill between Silver Gully and Pipeclay Creek. This agglomeratic rock appears to be rather of the nature of an intrusive igneous rock, filled with cognate inclusions.

The jasper has the same peculiar feature as that of the Hyde's Creek complex. The scree from the ridge covers the easterly slope, and through it there appear two small areas of vesicular quartz-magnetite-keratophyre like that north of jasper at Hyde's Creek.

Below the limestone on Pipeclay Creek, there is another intimate association of agglomerate and massive igneous rock (in this instance a porphyrite) in which it is difficult to distinguish between an agglomerate, and an igneous intrusion filled with inclusions. This has not been investigated yet. East of this mass, and extending from Silver Gully, across Pipeclay Creek towards Cope's Creek, is a band of very siliceous keratophyre. It is a grey rock, often containing small felspar-phenocrysts, very vesicular, and often amygdaloidal. The long amygdules are filled with calcite, or frequently with quartz or agate, while the microscopic features of the rock show further signs of the action of silicifying solutions. Occasionally the rock is traversed by veins of red jasper. In this case, also, there is no line of contact with the sediments exposed, nor is it obvious that the mass is an intrusion. It is very uniform in character, has a width of from fifty to a hundred yards, and is not associated with any obviously ejectmental deposits.

Petrographical Characters.

In the foregoing, the Devonian igneous rocks were classed into the dolerite-spilite series, the keratophyres, quartz-keratophyres, magnetite-keratophyres, and the variolites of Munro's Creek. They were briefly described in Part iii. of this series, but a more detailed account is now possible, and some modification of the former statements must be made.

1. *The Albite-dolerite and Spilite Group.*

General features.—These rocks are by far the most abundant of the Devonian igneous suite. Mineralogically and chemically, they form a very well marked homogeneous group; and, though the variety of textures developed is very great, they are connected with one another by a complete series of intermediate textures. At the acid extremity of the group there are passage-rocks into the keratophyres. The mineral composition is simple. Throughout the whole group, the predominant mineral is an acid plagioclase. Augite occurs in amount varying from one-fifth to more than one-half of the amount of the felspar. Ilmenite or titaniferous magnetite is next in order of abundance, but varies within wide limits, as does also the amount of apatite. Quartz varies greatly in amount, and in the rôle that it plays: it may occur in isolated grains, in interstitial mosaic, or in micro-pegmatitic intergrowth with felspar. Rarely a small amount of primary, brown hornblende is present. Pyrites is usually present, though only to a small extent. No definite sign of olivine is seen, even among the decomposition-products. Potassic minerals, such as biotite and orthoclase, are absent. The feature which distinguishes the whole group from rocks, similar in chemical composition and geological association in other parts of the world, is the comparative freedom from decomposition. Secondary minerals are present in most of the rocks, calcite, chlorite, or epidote, but usually only in small amount. Complete uralitisation is almost confined to the dynamically altered rocks of the Woolomin Series.

Chemical composition.—The chemical composition of this series is exemplified by the table herewith, and may be contrasted with the average composition of basalts as given by Daly(9). The chief feature of our rocks is their richness in soda, and, to a lesser extent, in titanium, (Daly points out that the two often go together) while the alumina, potash, and lime are low. The total iron oxides and magnesia, and the silica of the rocks free from quartz, are about the same as that of the average normal dolerite.

TABLE OF ANALYSES OF ROCKS OF THE NUNDLE DISTRICT.

	117	1002	1021	145	1109	1013	1086	1107	53
SiO_2 ...	48·22	48·35	51·19	54·88	48·61	60·39	56·95	48·04	49·06
Al_2O_3 ..	14·82	14·12	14·40	12·62	18·54	18·40	17·87	14·47	15·70
Fe_2O_3 ...	0·56	4·87	4·43	3·02	0·34	1·03	4·49	0·87	5·38
FeO ...	9·25	10·27	9·04	7·11	6·79	3·50	6·00	11·87	6·37
MgO ...	5·58	4·78	4·51	3·73	7·22	1·27	0·93	5·56	6·17
CaO ...	8·81	6·71	6·05	4·16	10·20	1·53	2·30	9·11	8·95
Na_2O ...	4·95	4·63	4·18	6·01	4·13	8·79	8·80	4·06	3·11
K_2O ..	0·44	0·38	0·78	1·10	0·18	0·46	0·38	0·64	1·52
H_2O+ .	2·54	2·00	1·82	1·76	2·02	1·37	0·71	2·15	} 1·62
H_2O- ...	0·15	0·30	0.24	0·23	0·20	0·20	0·38	0·13	}
CO_2 ...	1·40	abs.	abs.	tr.	1·19	1·70	0·91	0·26	—
TiO_2 ...	2·68	2·84	2·69	3·63	0·90	0·80	0·89	1·97	1·36
P_2O_5 ...	0·23	0·35	0·40	0·44	tr.	0·12	tr.	0·08	0·45
FeS_2 ...	0·37	0·22	0·19	0·71	0·04	0·02	0·04	tr.	—
NiO ...	0·03	—	—	0·05	—	—	—	—	—
MnO ...	0·23	0·18	0·21	0·25	0·08	0·08	0·08	0·21	0·31
BaO ..	abs.	0·10	abs.	abs.	—	abs.	—	—	—
	100·26	100·10	100·13	99·70	100·44	99·66	100·73	99·42	100·00

117. Spilite, Frenchman's Spur, Nundle. (See Part iii., p.704, N.T.415).
1002. Dolerite, Munro's Creek, Bowling Alley Point.
1021. Quartz-dolerite, Munro's Creek.
145. Quartz-dolerite, Hanging Rock. (Part iii., p.704, N.T.237).
1109. Variolite, Munro's Creek.
1013. Keratophyre, Hanging Rock, Nundle.
1086. Magnetite-keratophyre, Hyde's Creek.
1107. Dolerite in Serpentine, Chrome Hill, Bowling Alley Point.
53. Average composition of all basalts. (Daly, "Igneous Rocks and their Origin," p.27).

Mineralogical composition.—The high percentage of soda is expressed in the very acid nature of the plagioclase developed. If we calculate the composition of the felspar, assuming that all the orthoclase plays the rôle of albite in the plagioclase, we have the following table:—

No. 117. Felspar Molecules... $Or_4Ab_{80}An_{30}$ or $Ab_{74}An_{26}$
No. 1002. Felspar Molecules... $Or_4Ab_{74}An_{30}$ or $Ab_{72}An_{28}$
No. 1021. Felspar Molecules... $Or_9Ab_{68}An_{32}$ or $Ab_{73}An_{27}$
No. 145. Felspar Molecules... $Or_{12}Ab_{97}An_{15}$ or $Ab_{88}An_{12}$

Thus all the felspars, with the exception of the last, are oligoclase-andesine; the last is albite. Optical tests, however, show that all the felspar in the rocks is albite or acid oligoclase. The excess of anorthite molecule must be present in the pyroxene, which is abundant in the first three, but rarer in the last : the presence of some epidote and chlorite also removes some of the alumina that is reckoned in the calculation as if it formed anorthite. The felspars are often quite clear, and their position in the acid group is nearly always determinable from their positive biaxial character, and their refractive index which is lower than that of Canada balsam. More exact determinations are difficult. The Carlsbad twinning law has not been seen in combination with the albite law; extinction-angles measured on the albite lamellæ perpendicular to (010) give maxima between 8° and 16°, indicating a composition between acid oligoclase and albite. Prof. Becke's methods of investigation in convergent light are rarely applicable(**14**). A measurement made of the angle between the points of emergence of the optic axes of adjacent lamellæ of a pericline twin, indicates a composition of about $Ab_{85}An_{15}$, which again is within the limits expected. Occasionally, the felspars are slightly zoned, albite is at the margin, and oligoclase within. In the earlier account of these rocks, it was stated that andesine predominated among the quartz-dolerites. This is not confirmed by a more extended investigation. Andesine occurs but rarely, and the crystals of which it forms the central parts are strongly zoned. The determination of andesine in some slides remains doubtful owing to the dusty character of the felspar, and in other cases a testing of the Canada balsam shows that it has been insufficiently cooked, and has therefore a refractive index less than that of albite, leading to the above-mentioned error. It was reported, also, that spongy felspar occurred in one instance, though the mineral is usually compact; further search has not brought to light any other instance of spongy felspar than one described. In the porphyritic rocks, no difference can be found between the composition of the microlites and of the phenocrysts. Apart from its unusual composition, there is little to suggest that the acid felspar is not of primary origin. In one rock only has labradorite been found, namely, 1040, the specimen illustrated in Fig.1. The felspar forms clear fresh laths, and is associated with fresh augite, and chloritic decomposition-products of a glassy base.

The pyroxene, also, is generally fresh. Though in many cases there has been a small amount of chlorite, uralite, epidote, and calcite produced from the pyroxene, there is nothing that resembles the highly altered state of pyroxenes in most British spilites. No alkaline pyroxenes have been observed, nor any rhombic pyroxene. Dr. Cox suggests that the quartz-dolerite of the spilitic series in Wales(15) may be found to contain augite rich in the rhombic pyroxene molecule. The present series of rocks have been specially searched for this feature, and the optic axial angle of many crystals was measured by the graphical methods of Professor Becke. They proved to be very uniform in character; the value of 2V lay in nearly all cases between 42° and 48°. This is rather less than the normal value for augite, but does not prove the presence of enstatite-augite, in which the angle may diminish to zero. Calculation from the analyses shows, however, that some of the $RSiO_3$ molecule must be joined with diopside molecule in the pyroxene developed. There is no difference between the character of the pyroxene in a quartz-dolerite and that of a dolerite free from quartz. Sahlite-structure is never seen, though twinning is often present. The pyroxene is generally greyish-green in colour when seen in section, and in some of the more finely granular rocks it has a purplish tinge.

The hornblende has the usual reddish-brown colour of hornblende in basic rocks, is rarely present, and in small quantities only.

The ilmenite occurs in plates of very irregular size and shape, and, in more altered rocks, is frequently leucoxenised. The apatite and pyrites are as usual; the mode of occurrence of the quartz will be described below.

The Texture.—The distinction between the dolerites and spilites is one of grainsize only, and is a most indefinite one. There is a wide range of texture between which every gradation can be found. At the holocrystalline end of the series, the most marked type of texture is that of the intersertal quartz-albite-dolerites of Hanging Rock. In these, the crystallisation of the apatite occurred first, that of the ilmenite and augite followed; large prisms of plagioclase then formed, often with quite idiomorphic extremities; their outer portions are clear albite or oligoclase; the inner parts are often dusty and indeterminate; though generally acid, they appear at times to have a core of andesine. The mesostasis between these crystals is very varied in character: sometimes it is merely a quartz-mosaic of minute grains; or it may be a mosaic of minute grains of quartz and an untwinned felspar, which has the same refractive index as that composing the outer zones of the plagioclase crystals; or it may be a micropegmatitic intergrowth of quartz and felspar, radiating from the edges and particularly from the coigns of the large felspar crystals, and these micropegmatitic fringes may be narrow or may stretch across the whole space between the enclosing crystals. Again, the mesostasis may consist of a pericline-twinned mass of felspar, wrapping round the end of the plagioclase prisms that project into the interstitial spaces. Finally, there are instances of the whole interstitial space being occupied by a few large quartz-grains; this last type of mesostasis, though fairly common in the dolerites directly associated with the spilites, is absent from a purely doleritic mass like that of Hanging Rock. Apatite crystals are rarer in the mesostasis than in the main part of the rock; this is the reverse of a feature commonly observed in the quartz-dolerites(**16**).

With decrease in the quantity of quartz, the rock-texture becomes conditioned more entirely by the position of the felspar prismoids. In Munro's Creek, some of the dolerites have a strongly gneissic texture, owing to the parallel position of the felspars. Augite is generally fairly abundant, forming about a third of the rock; it is usually roughly idiomorphic. Ilmenite and apatite vary greatly in amount.

From this stage there is a passage into the ophitic texture, with a decrease in the size of the pyroxene crystals. Rocks with this texture are not so common as the former, and are among the purely doleritic sills, but the structure is most developed in connection with the passage-rocks between the dolerites and spilites (see Plate xxv., fig.2).

The majority of the rocks which we shall term spilites have the texture characteristic of the spilites of Germany, and differ from these only in their greater freshness. They are partially porphyritic or glomeroporphyritic. The glomeroporphyritic types have small ophitic aggregates of augite, felspar, and ilmenite, as well as isolated phenocrysts of the same minerals. The groundmass varies considerably; in some rocks it has a basaltic habit, but differs from basalt in the following peculiarity: the felspar phenocrysts have been enlarged, their outline is no longer sharp and rectilinear, but embayed, each embayment being filled with a grain of augite, on either side of which there project little tongue-like points of felspar (see Plate xxv., fig.3). Somewhat similar characters have been described by Rinne from the diabases of the Harz Mountains(17). There is usually no flow-arrangement of the felspars, and, though the rocks are vesicular in places, there is no special alteration in texture noticeable about the vesicles.

Another type of groundmass has much greater distinction between base and phenocryst, and a more marked flow-structure. This is very characteristic of the zone of spilitic rocks that extends north and south from Tom Tiger. The sharply bounded plagioclase phenocrysts have frequently microlitic extensions, giving swallow-tailed, or pronged terminations. The augite phenocrysts are moulded against the felspars, and do not show skeletal forms. Ilmenite and magnetite form long irregular aggregates of small grains. The groundmass consists of felspar, in the form of strips not much shorter than the phenocryst, and varying in size thence down to the finest microlitic dimensions. Its outline is rarely rectilinear; it has skeletal extensions, or is bent and twisted, forming shreds rather than laths. There is sometimes a general flow-arrangement; at other times the felspar is more radially grouped (a subvariolitic texture), or is quite irregular (see Plate xxv., fig.5). Associated with the felspars, are minutely granular augites and ilmenites; not infrequently the augite lies in narrow streaks between the felspar shreds. With decreasing grainsize, this texture becomes more and more confused, and the rock is more readily chloritised. Skeleton-crystals of augite occur, which are like rods made up of very minute grains, and feathered, one might say, with tiny plates of ilmenite. Such minutely granular augite is also frequently around minute laths of plagioclase. In many of these rocks there is more or less brown glass in the base (see Plate xxv., fig.6). The spilites are frequently vesicular, and sometimes, in the holocrystalline spilites, the vesicles are surrounded by hypocrystalline rock. One of the most remarkable types of rock is that in which an ophitic dolerite of medium grainsize has interstitial areas of fine-grained subvariolitic rock (Plate xxv., fig.2).

The amygdaloidal dolerite and holocrystalline spilites described above are characteristic of the non-pillowy masses of spilite and the central portions of the pillowy spilites all along the Frenchman's Spur, and the slopes north of Tom Tiger. The outer portions differ in being hypocrystalline. The phenocrysts and felspar microlites in the groundmass are sharply bounded, take on more distinctly the clustering radiating habit of variolitic rocks and are surrounded by a blackened border, full of skeleton-ilmenite and finely divided augite. In such rocks, there are frequently clear traces of flow-brecciation, the several fragments being sharply bounded in some places; in others they merge into the surrounding rock. These rocks show many structures within a short space, glassy, fragmental, or variolitic, solid or filled with lakelets of chlorite. In all these the felspars remain quite clear, and are acid oligoclase or albite. The extreme outer margin of one pillow in Swamp Creek exhibits a structure of which no parallel is known to the writer. It so closely resembles the plan of a pillow-lava that it may be termed the micro-ellipsoidal structure. It is probably a first stage in the formation of variolitic structure, preserved owing to the sudden quenching. The rock is broken up into small ellipsoidal portions about 0·2 mm. in diameter, consisting of radiating fibres of a dark brownish-green colour (chloritised augite ?), surrounded by a ring of clear epidote. This epidote is separated from the epidote in the adjacent micro-ellipsoid by a thin band of grey dusty material, which widens out into tricuspate areas at the point of contact of three micro-ellipsoids, just as does the material between the large ellipsoidal masses in pillow-lava. Within the micro-ellipsoids are phenocrysts of more or less epidotised plagioclase and fresh augite (Plate xxvi., fig.10).

Another type of structure occurs in the rapidly chilled rocks, particularly in the fragments of spilite in the agglomerates associated with the limestones. This has been already described, and is illustrated in a previous paper (Part iii., p.665, and Plate xxvii., fig.2).

Occurrences of various types of dolerite and spilite.—The two widest masses of dolerite are those on Munro's Creek and Hanging Rock. The first is about five hundred yards wide. Its eastern margin, against a fine-grained tuff, is a very fine-grained mass of uralite and chlorite, with a few phenocrysts (1041). A yard from the margin, the grainsize is larger (0·2 to 0·3 mm.), though the rock is still considerably decomposed. From this there is a gradual increase in grainsize inwards, and also an increase in the amount of quartz. A wide zone occurs lying from one hundred to one hundred and fifty yards from the boundary marked by a gneissic (fluxional) structure. The inner quartz-dolerite has the composition given on p.139 (1021), while the rock outside the gneissic band is free from quartz and has a lower percentage of silica (1002). A narrow fine-grained margin appears also on the western side of the mass, and is separated from the invaded rock (tuff-breccia) by a few inches of a finely granular aplitic rock which merges into the tuff. Under the microscope (1182) it is seen to be made up of small (0·05 mm.), equidimensional grains of albite, frequently free from twinning; at other times so finely laminated with albite and pericline twinning as to appear like microcline, save that its optical character is positive. A few small crystals of augite, and a little ilmenite are also present.

The large mass of Hanging Rock, which is half a mile wide, has an acid central portion. The rock figured on Plate xxv., fig.1 (1065), from the central portion of the massif, is much richer in silica than that near the margin, which contains 54% SiO_2 (see analysis 145). The grainsize does not vary noticeably across the massif.

The dolerite of the Possum Tunnel and elsewhere, near Bowling Alley Point, has been invaded by a coarse pegmatitic dolerite, consisting of oligoclase-albite (not andesine), augite, and large ilmenite-plates with a little interstitial quartz and plagioclase. The rock is rather crushed, and much veined with quartz, epidote, and calcite.

The long string of spilite-occurrences, running from north of Tom Tiger to the Oakenville Creek, have been already described. The spilite first analysed is one of these (117, N.T.415, Part iii., p.704). It has a complex texture; coarse phenocrysts and glomero-porphyritic aggregates occur in a spilitic groundmass in which are vesicles filled with calcite, and surrounded by fine-grained, subvariolitic, hypocrystalline material (see Part iii., Plate xxvii., fig.1). The spilites of Moonlight Hill have a partially granular, partially ophitic texture, and pass laterally into fine-grained spilitic masses. No special textural features are to be seen in the dolerite that contains axinite in its vesicles, save in the widely differing character of the material filling adjacent vesicles. Quartz, epidote, chlorite, calcite, and axinite occur singly, or in association.

A small sill crossing Moonlight and Madden's Creeks exemplifies best the porphyritic spilites with basaltic groundmass (Plate xxv., fig.4). Its vesicles contain quartz, which also appears to be replacing the rock metasomatically. Both magnetite and ilmenite occurred, but the latter is now changed to titanomorphite. The sill, though only four yards wide, is much more finely granular on the margin than within, though there is no alteration in texture or composition.

The spilitic rocks in the Woolomin Series are not so varied in texture. They are rather basaltic in character, and the phenocrysts are not very abundant. In one instance only has a pillow-like mass been found in the Woolomin rocks of the Nundle district. The rock of which it was composed consists of a few phenocrysts, clear plagioclase and uralite, set in a base of the same materials. The felspar of the groundmass is fresh, often untwinned, and very fine-grained (Pl. xxv., fig.3). Other rocks show the same original structure, but are more crushed. A few coarse-grained dolerites occur among these. They are also greatly shattered, traversed by shearing lines and long bands of crushed minerals. The felspar is difficult of determination, owing to the poor development of twinning, but it can never be said to have a spongy structure. The pyroxene is almost entirely changed to uralite.

The Variolites and associated Dolerites.

These rocks form a small group quite distinct from the normal spilite-dolerite series. Two occurrences may be noted as examples. The first is only a single narrow dyke traversing the cherts opposite Lyons' house in Swamp Creek. Variolitic texture is very well shown among the felspars, while the remaining minerals have become almost entirely changed to carbonates. The second mass is much larger and diversified. It occurs in Munro's Creek. The field-relationships have been described above. The breccia-like rock on the eastern margin(1090) consists of fragments of crystalline rock, set in a light yellow-brown glass, which is hypocrystalline, in places approaching to the character of the fragments which it includes. The most abundant of these inclusions are those least different from the groundmass. They are porphyritic with albite phenocrysts in a grey hyalopilitic matrix, containing many laths of felspar. The proportion of glassy to crystalline matter, and the extent to which flow-structure is developed, differ considerably in the several fragments, as do also the size and abundance of the phenocrysts. A second type of inclusion is holocrystalline. It contains fewer phenocrysts than the above, and has a pilotaxitic to trachytic base, consisting of albite laths with a little ferromagnesian matter, chiefly epidote and actinolite pseudomorphs after pyroxene. Wide variations occur in the extent of development of the flow-structure and the amount of ferromagnesian minerals. The type passes into the one first described. In addition, there are isolated crystals of albite, which project into the inclusions of the first-described type in a manner which shows that these inclusions were still plastic while they were in the glassy groundmass. There can be little doubt that this is a rock produced by the consolidation of a moving magma, which was shattered and the fragments were incorporated in the crystallising moving melt, which chilled and solidified rapidly. In other words, it is a flow-breccia. When decomposed, this rock appears in handspecimen like a schistose tuff. A thick band of it crosses the eastern branch of Munro's Creek.

The most peculiar rocks are the variolites. There are several types of these. The most aphanitic stage is a dense, pale green rock containing white spherical spots, which have no definite outlines. It occurs in a narrow pillowy mass on the western-most tributary of Munro's Creek, and again on the main creek near the Razorback(1034, 1089). Under the microscope, it is seen to possess a grey-green base divided up into acutely angular portions separated by straight colourless rods running in all directions(Pl.xxvi.,f.9). These rods are quite sharply bounded, but their nature and composition cannot be determined. They suggest felspar by their appearance, but are untwinned and divided into irregular lengths, each occupied by a single transparent mineral, different in optical orientation from its neighbours. The elongation of these short portions of the rods may be positive or negative. Professor Gregory has described similar structures in the variolite of the Fichtelgebirge(18), and Michael Levy in that of Durance(19).* These authors suggest that these may be contraction-cracks filled with secondary felspathic material. The same explanation may hold for the rocks under discussion, but it is difficult to account for the absolute rectilinearity of the structures. Where these rods intersect, there are occasionally radiate spherulites of felspar (varioles). The angular spaces between the rods are composed of very fine green fibres, with a radial or curved arrangement about one or more centres, often recalling the arrangement of the line of force about a bar-magnet. They lie in a colourless, weakly birefringent groundmass. The greenish fibres extinguish at small angles, and are probably chlorite. No primary minerals or recognisable pseudomorphs occur in these rocks. In a more crystalline stage of this rock, the chlorite plates are more individualised; large plates are associated with

* For a summary of all the earlier work on variolites, see Gregory and Cole's paper, "Variolitic Rocks of Monte Génèvre," Quart. Journ. Geol. Soc., 1890.

epidote and are probably pseudomorphs after plagioclase. The rod-like structures still persist, but are either less well marked, or are emphasised by the development in them of lines of magnetite, or they are completely hidden by secondary minerals. Other types of variolite are porphyritic; they contain (*e.g.*, 1007) phenocrysts of decomposed augite and plagioclase, in a confused more or less variolitic base, composed of laths and skeletal forms of felspar, together with a little uralite, epidote, and chlorite; a little secondary quartz is scattered about in small irregular patches.

Associated with the rocks just described, is a very beautiful variolite which consists chiefly of felspar with a little interstitial augite. The characteristic radiating structure is well shown (Plate xxvi., fig 7). This rock forms the outer part of a pillow; it is unfortunately too decomposed to be suitable for chemical analysis, and there are in it abundant veins of pennine and clinozoisite. The felspar seems to be oligoclase, but its exact composition cannot be determined optically. In another rock with a similar groundmass there are numerous phenocrysts of albite(1078). The freshest rock, and the one that has been analysed(1109), has a texture intermediate between the variolitic and ophitic types, with a few phenocrysts. These consist of andesine; the felspar of the groundmass is rather more acid, being a basic oligoclase, with a small extinction-angle, but with a refractive index greater than that of Canada balsam. The augite is partly ophitic, partly in narrow, irregular grains or prismoids. There is a little scattered chlorite, but isotropic, probably colloidal, chlorite occurs, with a small amount of carbonates, clinozoisite, epidote, and a trace of pyrites. The analysis confirms the optical evidence of the basicity of the felspar developed, and the absence of any ferric minerals.

There can be little doubt that these rocks are members of the Middle Devonian series, but their greater richness in lime is not at present explicable.

The Keratophyres.

The keratophyres are a varied group of rocks which consist almost entirely of acid plagioclase. They are connected in two ways with the dolerite-spilite series. Quartz-dolerites, becoming richer in quartz and albite, pass into quartz-keratophyre. Many intermediate rocks have been found. The rarer type of passage is that in which, by decrease in the amount of pyroxene and increase in the iron ore of a spilitic rock, a black slaggy rock is produced, to which the name magnetite-keratophyre may be applied. Far more common, however, is the association of magnetite-keratophyre with keratophyre proper, quite apart from any passage into the spilite-group.

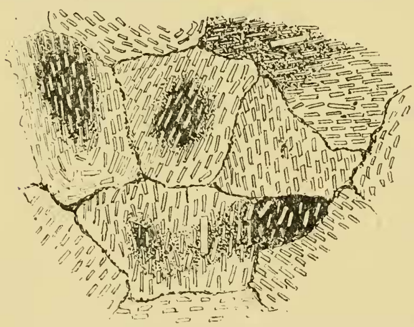
The true keratophyre is represented by the sill at the head of Oakenville Creek. It consists(1013) of almost pure albite, not acid oligoclase as stated in the earlier account. The analysis, making the same assumptions as before, shows that the felspar has the composition Ab_9An_1. There is, in addition, a little magnetite, limonite, chlorite, and carbonates. In some specimens there are little rods of hæmatite, which may be pseudomorphous after hornblende. (There are little pseudomorphs of this character in the porphyries of the Nundle district.) The texture of the keratophyre is trachytic, but not markedly so, and the laths are of uniform size, being about a fifth of a millimetre in length, with a few small phenocrysts (Plate xxvi., fig.11).

Just north of Folly Creek, near the track to Bowling Alley Point, is a slag-like rock(1084) with well marked trachytic habit, consisting of albite, magnetite, and chlorite pseudomorphous after augite. The magnetite is very abundant, and occurs in exceedingly minute but well shaped crystals. The felspar is in clear laths and microlites. This is an example of the passage-type between a spilite and a magnetite-keratophyre. It differs from the usual type of the latter rock in being quite massive, with little or no scoriaceous habit.

The keratophyre-complex by Hyde's Creek yields the most interesting types. The pinkish-white nodular rock to east and west of the magnetite-keratophyre, is made up of small fragments of very trachytic rock, the flow-directions in the several fragments lying without any regard to the flow-directions in adjacent fragments(1108). Each fragment is made up almost entirely of albite laths, the larger laths lying in a matrix of exceedingly minute microlites and a little quartz. The felspar is often very fresh, but some kaolinisation has taken place, spreading outwards in bands from the cracks separating the fragments of which the rock is composed. The reddish colour of the rock is due to the oxidation of scattered grains of pyrites.

Magnetite enters into these rocks in a variety of ways, one of the most remarkable being that seen in the nodular magnetite-keratophyres (1096) [Plate xxvii., fig.3]. The rock is divided up into roughly polygonal masses about four millimetres in diameter. Each polygon consists of an outer rim, rich in finely crystalline magnetite in a network of albite microlites. There follows within a zone of varying width, consisting of a finely granular mosaic or lathy felt of albite, which sometimes contains large, clear phenocrysts of the same mineral. There is usually no general circumferential or centripetal arrangement of the felspar laths within a nodule, but frequently a general trachytic structure continues without interruption throughout the whole nodule, and may be parallel or inclined to the trachytic arrangement in adjacent nodules. Besides the albite, a little chlorite may occur in this zone. Within this is a narrow passage-zone of felspar laths, sometimes more or less kaolinised, and containing rather abundant dusty magnetite. The inner part of the zone may be coloured yellow by the abundance of the oxidised chlorite. The central portion is of normal magnetite-keratophyre, composed of albite laths and abundant magnetite. Albite phenocrysts occur in this, and may project, quite unaltered, right out into the clear felspathic zone, or may even traverse two or three zones, retaining the general trachytic direction of the nodule. The above is the most complete type of polygonal nodule; in others less well developed, some of the zones may not be present. In a few instances, the central magnetite-keratophyre, with its more or less marked texture, is wrapped round by a zone of keratophyre free from magnetite, in which the laths have a circumferential arrangement. The boundaries of the several zones are never sharp. Where spaces occur between the nodules, they are filled with a mosaic of chiefly untwinned felspar. Except for the abundance of magnetite, this rock is allied in structure with the purely felspathic brecciated keratophyre last described.

There are also rocks of a more obviously brecciated appearance, angular fragments of black rock in a pinkish background. These show a brecciated structure similar to that of the foregoing; that is, they are divided up into areas, in which the general direction of the trachytic texture has no relation to that in the adjacent areas, and this diversity of flow-direction is seen both in the parts rich in magnetite and in those free from that mineral. As in the last rock, also, albite crystals may project from the dark ferruginous part into that surrounding it, which is composed entirely of felspar. The limits of the ferruginous parts are quite irregular; though, in handspecimen, they may appear to be very sharply bounded, under the microscope, they are seen to pass into non-ferruginous parts (Pl.xxvii.,f.4). In a few instances, the magnetite-keratophyre fragments are wrapped round by purely felspathic rock, in which the felspar laths are arranged circumferentially about it. Magnetite may also occur in cracks traversing the rock, sometimes running between adjacent trachytic patches, sometimes cutting across a single fragment. There are also segregations of magnetite lying isolated in areas usually free from that mineral. Chlorite occurs in large flakes. As regards actual mass, the magnetite is considerably less abundant than the felspar, but the very minute grains and crystals are so abundant that they render the whole portion of the rock in which they occur almost black. Fig.6 is a diagram showing the structure of these rocks. For clearness' sake, the size of the felspars has been enlarged proportionately to that of the individual rock-fragments.



Text-fig.6.—Diagram showing the structure of a brecciated magnetite-keratophyre.

A variety of the brecciated structure is seen in a few rocks, in which the fragments of trachytic rock are not in contact with one another, but are separated by a matrix of minute equidimensional grains of felspar, either untwinned, or twinned with exceedingly minute lamellæ. Quartz may also occur in this mosaic, but its determination is difficult. The trachytic fragments may be entirely felspar, or may be homogeneous magnetite-keratophyre, but generally they are keratophyre with a magnetitic core, and purely felspathic outer parts. Complementary to this type of rock, there is still another (1188) in which the non-trachytic matrix predominates, and is grey-coloured owing to a regular distribution of magnetite throughout; the inclusions are felspathic trachytic keratophyre, and sometimes contain a magnetitic core. Even in this rock there is a concentration into lines between the inclusions, giving a honeycomb-appearance. (Plate xxvii., fig.1).

In other rocks, the magnetite is more evenly distributed, and the rock begins to take on a more slaggy or scoriaceous habit, and its rough, irregular cavities are filled with calcite. After having removed the carbonate by hand, as far as was possible, during the rough crushing of the rock (1086), the remainder was analysed, with the result given(p.139). This confirms the optical determination of the felspar as albite, for the composition of the felspar, calculating from the analysis in the same way as before, should be $Ab_{10}An_1$. The amount of titanium present is rather less than might have been expected from an analogy with the chemical characteristics of the spilitic series. The same features are even more strongly developed in the very richly magnetitic keratophyre shown in Plate xxvi., fig.12. The association of areas rich in magnetite with others poor in that mineral, sometimes merging into one another, sometimes sharply defined, and the strongly marked trachytic texture, with occasional brecciated structure, are also distinctive features. The rock is strongly attracted by a magnet: the felspar is apparently pure albite and water-clear, but the rock is so scoriaceous, and so intimately mixed with calcite, that density-determinations or chemical analysis would be of little use.

Some of the magnetite-keratophyres of this complex contain more or less quartz. In one(1060) near the margin of the mass, the richly magnetitic areas lie in a matrix of quartz-keratophyre, in which some, at least, of the quartz is of secondary origin. Another of these rocks differs in that the magnetite occurs not only in finely divided masses, but in irregular aggregates from a tenth to a fifth of a millimetre in diameter. The rock(1110) has a brecciated structure, and the magnetite is segregated chiefly in long, irregular bands running between adjacent fragments, and in close association with the secondary quartz and calcite. It also occurs impregnating the central parts of some of the fragments. Apart from the presence of magnetite, the rock is similar to the quartz-keratophyres to be described below.

The magnetite-keratophyre that lies north of the jasper band differs from the above in having an amygdaloidal character. The vesicles are filled with quartz, and sometimes have a selvedge of chalcedony. The rock consists of a felt of albite-laths and small phenocrysts in a matrix darkened by dust-like magnetite; the latter is, for the most part, evenly distributed, but may be aggregated around the vesicles.

The magnetite-keratophyre of Silver Gully is similar to the rock last described. It is associated with a small patch of dense, slaggy, very heavy magnetite-keratophyre, similar to the most ferruginous parts of the Hyde's Creek rocks. As already mentioned, this mass of keratophyre seems to pass into a locally brecciated sill of dolerite, which extends about half a mile northwards. This dolerite has been more or less silicified in places, and more carbonates have been introduced. The dolerite of the Hyde's Creek complex, though it is not so intimately connected with the keratophyre, closely resembles the Silver Gully rock. It is very acid; indeed it may be considered as a passage-rock between dolerites and quartz-keratophyres: it consists of albite, chloritised pyroxene, and abundant interstitial quartz, together with a little ilmenite locally changed to sphene. The rock is rather crushed, and carbonates have been introduced into the zones of granulation.

Adjacent to the dolerite in the Silver Gully complex, is a fairly coarsely granular quartz and felspar rock which appears, at its eastern side, to be a massive quartz-keratophyre-porphyry, but which passes without a break into an obviously brecciated rock, filled with fragments both of igneous rock and of limestone. A microscopical examination of the apparently massive rock shows that it also is brecciated. It consists of large shattered crystals and angular fragments of quartz and felspar in a fine-grained felsitic base. Even more remarkable is the agglomeratic rock on the summit of the ridge between Silver Gully and Pipeclay Creek. This consists of a varied collection of rounded or angular fragments of porphyritic or trachytic keratophyre and magnetite-keratophyre in a matrix of trachytic keratophyre. Though there are no lines of contact with the sedimentary rocks exposed, it seems reasonable to consider this mass as the product of the intrusion of a keratophyre-magma filled with cognate xenoliths.* This is an extension of the conception of a brecciated intrusion which is necessary to explain the structure of the Hyde's Creek keratophyre.

The main series of rocks to which the name quartz-keratophyre is most directly applicable, run along the eastern side of Silver Gully, across Pipeclay Gully to Cope's Creek. Their macroscopic features have been already described. The composition of the rock is fairly uniform throughout, but variations occur. The predominant mineral is acid felspar. This generally, but not always, forms phenocrysts lying in a pilotaxitic, trachytoid or panidiomorphic granular base. With these are sometimes phenocrysts of augite with a large optic axial angle. The plagioclase of the base is rarely easily determinable, being often rather dusty: it does not appear, however, to be more basic than oligoclase. Augite may occur in the base as small prisms, but is generally changed to chlorite: magnetite, ilmenite or titanomorphite may occur in small amount. The greatest diversity arises in the mode of occurrence. A few of the rocks in this mass are free from quartz, but the majority contain it in a manner which raises suspicion as to its primary character. It may be interstitial, or form in little irregular patches against which the felspars are moulded, or it is present in intimate

* Compare with this the "Eruptive pseudo-conglomerate" described by Clements(5), p. 135.

micrographic intergrowth with the felspar. In the last case, there can be no doubt that the quartz is primary. The larger grains apparently replace portions of the felspar-felt, and in no way resemble corroded phenocrysts, but have more the appearance of secondary introductions, especially when they occur in zones characterised by more than the usual amount of calcite or chlorite. Finally, in several of the rocks the quartz-grains are completely surrounded by chalcedony, which extends outwards into the felspar of the rock-matrix. This is clearly a secondary enlargement of the quartz-grains, and we may note at the same time, the abundance of chalcedony in the vesicles of some of the rocks. Chlorite and calcite also occur in the vesicles either singly, or in association with each other.

The Post-Peridotitic Dolerites..

These rocks form dykes in the serpentine, chiefly on the northern slope of Chrome Hill, and also in a small patch of serpentine that occurs west of the Peel River, south of Warden's homestead. They are usually very crushed and altered. The freshest rock(1107) has a very peculiar structure It is partly granulitic, the base consisting of angular or rounded grains of augite in a groundmass of platy felspar. There are a few large felspar-phenocrysts, and some ophitic glomeroporphyritic aggregates of felspar and augite, as well as isolated grains and crystals of augite. The pyroxene is pale in colour, and though there is no noticeable purplish tinge, hour-glass structure may occasionally be seen. The optic axial angle 2V is 51°. No difference is observable between the augite of the phenocryst and that of the smaller grains. Both are very fresh, though chlorite is abundant, at times pseudomorphous after augite. The plagioclase is not easily determinable. Some large zoned crystals occur, showing refractive indices greater than that of Canada balsam, but the extinction-angles do not yield determinative readings. The felspar of the groundmass is very dusty, and is frequently decomposed to a cloudy mass of epidote and clinozoisite. It seems to have the optical characters of an acid andesine. The composition calculated from the chemical analysis (see p.139) is

$Ab_{1\cdot9}An_1$. Titanomorphite is very abundant, occurring in irregular grains or in long saw-like rows, as if developed from an ilmenite-plate. No undecomposed ilmenite remains.

More common than this are rocks which might be termed proterobases. They are more or less crushed and altered, and contain a reddish-brown hornblende, which forms isolated grains or peripheral intergrowths with the augite. The latter is generally fresh and similar to that in the rock last-described, though its optic axial angle may reach as low as $2V = 42°$. The felspar, on the whole, may be a little more acid. An outer zone of albite sometimes appears around the andesine-kernel, but an exact determination is rarely possible. Ilmenite is generally replaced by titanomorphite, and a very little apatite may sometimes be seen. The structure varies from granular to ophitic.

These rocks differ from the post-peridotitic dolerites of the Barraba district, and also from the spilitic group of rocks, though their chemical analysis repeats most of the features seen in the analyses of the spilitic rocks.

General Discussion.

The observations, of which an account has been given, raise a number of interesting and difficult problems. The most striking feature of the whole series of the Devonian igneous rocks is their richness in soda. This character they share with the spilitic rocks of England, and it will be of interest to see how far the explanations offered for the nature of these rocks are applicable to ours, and what alternative views may be considered.

Messrs. Flett and Dewey consider that the albite in the British spilite-lavas is secondary(2). They believe it to have been produced by a pneumatolytic change affecting the rocks shortly after their solidification. Solutions, rich in soda, traversed the rock, attacking, and replacing by albite, the originally basic felspar, and, at the same time, changing the pyroxene to chlorite, epidote, and calcite. The intrusive albite-dolerites are equally albitised, but, in them, the pyroxenes are rather better preserved. The secondary nature of the albite is seen by its spongy character. Associated with the English albite-dolerites is a hornblende-proterobase (minverite) in which the albite is chiefly primary, though a small amount of albite basic felspar may be recognised. The quartz-diabases in the same series are not albitised at all. By the escape of the sodic solutions from the igneous rock into the surrounding mudstones, adinoles are produced. The occurrence of the minverites shows that albite may crystallise directly from a differentiate of the spilitic magma, although, in the British rocks, according to this view, it was usually segregated into post-volcanic solutions that attacked and replaced the originally crystallised basic felspar. Bowen(**22**) and others describe the development of albitic facies in the upper portions of doleritic masses, and the escape of the albite into the overlying sediments, producing adinole. Bowen believes that the albitic rocks are the result of the intrusion of gabbroid magma into argillites, and that the water contained in the sediments has taken part in the transfer of the albite-molecule out of the normal magma. Daly supports this view, believing that the examination of sills, from the top to the bottom, will show an upward enrichment in albite. "The submarine origin of the pillow-lavas implies that the magma passed through wet sediments of greater or less thickness. Under these conditions, water-gas must play an important rôle in modifying the magma in the vents, and it seems impossible to doubt that, occasionally, the upper part of the magma-column, and also some of the extruded lava, will become albitised. Meanwhile, the general body of the igneous rock must often be profoundly altered by the absorbed water-gas or hot water, exactly as described by many authors writing of the spilitic masses. . . . . . The writer believes that the spilite rocks are pneumatolytic derivatives of normal basaltic magmas, and that the modifying gas is chiefly water of resurgent, not of juvenile origin."(**9**, p.340).

The spilitic rocks of the Nundle district differ from the majority of those discussed by Messrs. Flett, Dewey, and Daly, in the almost complete absence of signs of secondary origin of the felspar, and the rocks as a whole are fresh. Clear albite prisms may occur in ophitic intergrowth with undecomposed pyroxene, a thing difficult to explain on the hypothesis of the secondary origin of the albite, unless, in some circumstances, albitising solutions have no action on pyroxene. Certainly some decomposition-products occur, chlorite, epidote, and calcite, but they are not abundant, save in rocks that have obviously been in solution-channels (*i.e.*, shear-lines, and the boundaries of some sills) or have suffered the intense pressure that affected the rocks of the Woolomin Series. It must be noted, however, that our rocks are rarely, if ever, flows, and, as Messrs. Flett and Dewey have observed, pyroxenes, as a rule, are better preserved in the intrusive than in the extrusive rocks. Further, in the examination of the wide sills, there is no sign of greater albitisation of the upper parts. One cannot say definitely which is the upper part of the great sills on Munro's Creek and Hanging Rock, but it seems clear that the rock is equally albitised throughout a width of more than five hundred yards. The western, and probably upper side of the former mass contains veins of albite-dolerite-pegmatite. Another point of difference from the British spilitic rocks is the albitic character of the felspar in the quartz-dolerites. Certainly, in some quartz-dolerites, zoned felspar occurs, of which the central portion is andesine, but it is not usually present. They are, however, with the single exception noted, the only rocks in which felspar more basic than oligoclase is to be found.

Again, adinole is not developed along the contact of dolerites and cherts. Two specimens were analysed, which should have had every opportunity of becoming albitised had sodic solutions escaped from the cooling magma. These are (A) the chert in the mass between the pillows of spilite, illustrated in Fig.2b, and (B) the secondary chert from the specimen shown in Fig.1, in which the felspars of the invading dolerite(1040) are clear well crystallised prisms of labradorite. C and D are respectively radiolarian chert and cherty shales from the Tamworth Common. (A narrow sill of albite-dolerite occurs here, but, from the descriptions of Messrs. David and Pittman(12), it does not appear to have been in contact with these two rocks). The figures are those determined by Mr. Mingaye. E and F are from slightly altered, aud completely altered sediments, that are changed into adinole where they are in contact with diabases of the Harz Mountains.

	A	B	C	D	E	F
SiO_2 ...	67·87	70·06	91·06	80·50	69·27	75·25
Na_2O ...	1·10	1·04	0·28	1·18	2·25	7·54
K_2O ...	2·08	1·08	0·84	1·68	4·31	0·61

It is clear that the cherts from the Nundle district do not contain any noteworthy amount of albite. On the other hand, the presence of the albite-aplite above the Munro's Creek sill, shows that locally there was some slight albitic extrusion from the magma.

Termier has explained(35) the albitisation of some Alpine diabases, by the supposition that soda-bearing soil-waters draining off gneissic areas on to diabases may bring about a replacement of lime by soda, concurrently with the decomposition of the ferromagnesian minerals, and he has brought forward an interesting series of analyses in illustration of this. From the nature of the case, this hypothesis is quite inapplicable to the explanation of the Nundle rocks.

It seems permissible to suggest that albite in spilitic rocks may be either a direct magmatic crystallisation, or may have been concentrated into the magmatic aqueous solutions, and have then replaced the first-formed basic felspar. The albite of the Nundle dolerites and spilites, like that of the British minverites, seems to be chiefly primary. This does not preclude the possibility that it may be largely secondary in spilitic rocks in adjacent areas. The conditions, that would determine the one mode of crystallisation or the other, probably depend on the amount of water in the spilite-magma, its source, and its mode and time of escape.

In the keratophyres, there can be no doubt that, at the end of the sequence of differentiations, the magma was very hydrous, and post-volcanic processes were very active. The felspar of these rocks is almost pure albite, but even here there is no evidence of the secondary nature of the felspar. Neithammer, from a study of some Javanese rocks, concludes that the keratophyres may be albitised porphyrites(23). Sundius states that the felspar of the magnetite syenite-porphyry of Kiruna, Lappland, though originally acid, has been still further albitised(22). Nothing analogous to the features claimed by these authors as evidence of albitisation, has been noticed in the keratophyres of the Nundle district.

The development of magnetite in the keratophyres presents many features of interest. So far as can be learnt, the only rocks, at all analogous to these, are the Pre-Cambrian magnetite-syenite porphyries of Lappland, and a few isolated and less investigated occurrences in the Urals and elsewhere. The analogy is very clear, if we compare our rocks with the descriptions and illustrations in the papers of Sundius(23), Geijer(24, 25), and Lundbohm(26). Sundius, while employing Geijer's term, magnetite-syenite-porphyry, suggests that keratophyre would be a more suitable designation. It will be of interest, therefore, to summarise the views that have been put forward as to the origin of the Scandinavian rocks. The magnetite-syenite-porphyries are in intimate association with great deposits of iron-ore, and the explanation depends on the view adopted as to the origin of the iron-ores. Bäckström considered the iron-ores were of hydro-pneumatolytic origin, belonging to the last phase of volcanic activity(27). The volatile iron-salts rose through the igneous rocks, and, coming into contact with the sea-water above, were precipitated as magnetite. This hypothesis was supported by De Launay(28). On the other hand, Högbom considered the ore was the result of a differentiation from a syenitic magma(29), and Stutzer supported this view, adding to it the statement that pneumatolysis has played an important minor rôle in the formation of the ore(30). Geijer has studied the question in great detail. His monograph on the Kiruna field(31) is, unfortunately, not accessible in Sydney, but he has published an abstract of it in Economic Geology(24), and, more recently, a general review of the mode of occurrence of the iron-ores of Lappland(25). He supports the view of the magmatic origin of the iron-ores, as also of the magnetite-syenite-porphyries, believing that the latter differentiated out from the normal syenite-porphyry of the district, and had a lower temperature-range of crystallisation. He cites the researches of Lenarcic(**32**), and Day and Allen(**33**) on the lowering of the viscosity produced by the presence of a small amount of magnetite in an albite-melt, and notes that the eutectic albite-magnetite ratio of three to one, as determined by Doelter(**34**), seems to be a frequent one in the magnetite-syenite-porphyries. At the same time, he recognises the presence of a certain amount of pneumatolytic action, affirming that the ores stand in pegmatitic relation to the parent-magma, there being evidence for the presence of a considerable amount of magmatic water. (Apatite occurs with the ores.) His view differs from that of Stutzer chiefly in the advocation of an effusive, not intrusive, origin for the syenite-porphyries.

The most significant features of our rocks seem to be the following: they solidified from a magma under non-uniform pressure, and hence are not only strongly trachytic, but were broken up as they solidified, and the keratophyres now consist of closely compacted, minute fragments of trachytic rock, usually without any matrix, occasionally with a matrix of non-trachytic acid keratophyre, a consolidation of the residual magma under static conditions. Most of the fragments have preserved the straight direction of the flow-structure, some have been bent, some have been actually rolled up into a concentric arrangement, and this is most frequent when the fragment has a kernel of magnetite-bearing rock. The magnetite-keratophyre forms the central portion of the keratophyre-mass; around it is a zone of particoloured nodular or breccia-like mixtures of magnetite-keratophyre with purely albitic rock. In these, the distribution of the magnetite is most irregular, but, in the main, it is suggestive of the occurrence of two periods of crystallisation. It rarely, if ever, occurs as inclusions in the crystals of felspar, but lies in an extremely divided state between the felspar-laths. Part of it is segregated into nodules of rounded or irregular shape, sometimes broken across by the brecciation, and here showing a sharp fractured boundary, but more usually without any sharp boundary, passing out into the albitic rock, which may have a continuous rectilinear flow-direction, or may bend to more or less encircle the dark portion. This seems to show that the presence of magnetite toughened the rock against brecciation, which occurred either during the crystallisation of the felspar, forming the kernels around which the last-formed laths might wrap themselves, or immediately after the consolidation of the felspar, in which case the trachytic structure of the particular fragment would pass unhindered through the magnetitic nucleus. The latter is the more usual feature. The first epoch of crystallisation of the magnetite seems to have been a magmatic one: the magnetite-keratophyre and keratophyre proper must be differentiates from a common magma, and the peculiar mixed rocks form the transition-zone of incomplete differentiation. After consolidation and brecciation, there still remained a residual magma which consolidated between the fragments. This granular mesostasis may consist of quartz and albite, of quartz, albite, and magnetite, of quartz and magnetite, or of magnetite alone. The last two types of matrix sometimes form in such narrow crevices between the fragments, or in cracks traversing them, that it seems most probable that they are of the nature of hydro-pneumatolytic veins. In confirmation of this, we may note that they slightly impregnate the rocks on either side of the vein. In one specimen, the mesostasis retained nearly all the magnetite(1188). The nodular segregations of magnetite are quite different from those in the Scandinavian rocks, which, according to Bäckström, are vesicles filled by pneumatolytic deposits of magnetite, but, according to Geijer, are "concretionary bodies in the porphyries, and have crystallised under igneous conditions, and pass into the normal groundmass on the one hand, and into true vesicles on the other."(**25**, p.715).

Within the zone of these mixed brecciated keratophyres, lies the main mass of magnetite-keratophyre of the Hyde's Creek complex. It is much more uniform, and brecciation is not so very marked a feature. The slaggy, vesicular character is doubtless due to the former presence of magmatic gases, and the rough, non-amygdaloidal shape of these cavities is, perhaps, explicable on the assumption that the rock moved in jolts by successive brecciations of almost solid rock, and not entirely by steady viscous flow.

In the quartz-magnetite-keratophyres, brecciation is rarely seen. The vesicles are abundant, and are rounded or amygdaloidal. All the magnetite seems to have crystallised in the earlier period. As we pass to the quartz-keratophyres, there is increasing evidence of the action of silicifying waters, not only in the filling of the vesicles with quartz and chalcedony, but in the attacking of the rock itself, the formation of rings of secondary silica, quartz or chalcedony around the original quartz-grains, and the replacement of small parts of the rock-fabric by a finely granular quartz (agate?) mosaic.

The jaspers associated with the keratophyres are the last product of the spilite-keratophyre magma. Narrow veins of jasper occur in the keratophyre, and large independent masses are developed, which were deposited by successive bodies of siliceous solutions, rising through fault-planes, metasomatically replacing the country-rock, and depositing quartz and chalcedony, together with the last of the iron-ore, now completely oxidised to hæmatite. The last of the magmatic solutions, too feeble to form jaspers, have merely jasperised, and reddened, with hæmatite, the banded radiolarian cherts.

Thus the evidence of our magnetite-keratophyres series leads to the conclusion that they primarily originated by magmatic differentiation, but that hydro-pneumatolysis played an important minor rôle. This accords, to a great extent, with the views of Högbom, Stutzer, and Geijer, as to the origin of the Lappland rocks. The structures developed have been explained as the result of varying degrees of viscosity in the crystallising magma. Recapitulating, we have the following table :—

1. Pure albite-magma, with no vesicles or sign of pneumatolysis. Viscosity extremely high, amounting to partial rigidity; brecciation a very marked feature. The trachytic structure is probably the result of crystallisation under non-uniform pressure, rather than actual flow.

2. Albite-magnetite-magma, with a few irregular vesicles, and slight evidence of pneumatolysis. Less brecciation than in No.1, and more evidence of viscous flow.

3. Albite-magnetite-quartz-magma, with abundant smooth-walled vesicles, and evidence of the presence of magmatic water. Still further diminished viscosity, brecciation practically absent, and flow-structures more obvious.

4. Quartz-albite-magma, with abundant amygdules filled with silica, and evidence of the former presence of much magmatic water. No sign of brecciation, but every indication of considerable fluidity.

5. Quartz, chalcedony, and hæmatite, deposited from aqueous solution.

The knowledge of the relation between magma-viscosity and chemical composition is at present very imperfect(40), particularly in regard to the quantitative effect of fluxes, such as water; nevertheless, the sequence given above seems to accord with what might have been anticipated.

So far, only those jaspers that are immediately adjacent to the spilites or keratophyres can be said to have been derived from this source, and such jaspers are as yet known in the Bowling Alley Series only. The mode and period of origin of the far more abundant jaspers of the Woolomin Series are not yet known. They show many of the features common to the other jaspers, though they are more uniform in character, and less vein-like. The writer concurs with Professor David's present opinion, that they are mainly of secondary origin, alteration-products or metasomatic replacements of country-rock. They can hardly be merely ferruginous, abyssal oozes, as formerly suggested.

The formation of ferruginous jaspers and iron-ores by solutions derived from spilitic magmas is not without analogy. The same mode of origin has been claimed for much of the Lake Superior iron-ore(37), as also for the ores of the Rhenish Schiefergebirge in Germany(39) and elsewhere. In these cases, however, the iron-bearing solutions are believed to have escaped from basic lava-flows, and not after extreme differentiation.

Difficulties arise when one endeavours to determine the conditions under which the series of eruptions took place, which produced the rocks described. The spilite-pillows must have invaded sediments that were still watery, and capable of fluid movement; therefore, the magma must have come near to the surface (the sea-bottom), during the period of deposition. The more deep-seated magma (the dolerites), encountered consolidated sediment, and have rough, shattered lines of contact with the rocks they invade. The keratophyres, in particular, must have formed at some depth, and only after the complete consolidation and some faulting of the specimens. But the stratigraphical record shows that there was no important faulting or folding from Middle Devonian to Lower Carboniferous times, and we must accordingly consider these faults as merely local movements around the centres of Middle Devonian, submarine, igneous activity.

The discovery of the agglomeratic keratophyre, between Silver Gully and Pipeclay Creek, throws some doubt on the former assumption of a single ejectamental origin of the "tuffs," "breccias," and "agglomerates" of the Devonian stratigraphical succession. When first these rocks were discovered in the Tamworth district, they were considered as sills by Professor David(**38**), though later, upon the evidence of their microscopic structure, he stated that they were tuffs, and termed "intrusive tuffs" certain occurrences in which the relation of the igneous to the sedimentary rock seemed to be an intrusive one. More recently, the so-called tuffs in the Silurian Series, east of the Jenolan Caves, have been proved by Mr. Süssmilch to be really strongly differentiated, intrusive porphyries full of inclusions, not only of cognate igneous rocks, but of fossiliferous limestone, and the enclosing cherts and slates. The writer has seen these, under Mr. Süssmilch's guidance, and has noticed some analogy (first suggested to him by Professor David) between them and the agglomeratic rocks of the Tamworth Series. This analogy does not amount to a parallelism, however. In an earlier communication, the writer suggested that the apparently intrusive character of the acid tuffs into the Devonian chert might be due to the drying and cracking effect of hot ash falling on to damp mud. Other exposures have now been found, in which this explanation is inapplicable. In Swamp Creek, for instance, is a mass of acid igneous rock, resembling what has been termed "acid tuff," but clearly intrusive into the chert, and containing fragments of *Heliolites*, etc. Microscopically, it is entirely crystalline, and consists of shattered and corroded grains of quartz and albite in a finely granular felsitic mosaic. One may also recall the brecciated keratophyre that passes into calcareous agglomerate near Silver Gully. Another significant feature is the almost entire absence of glassy matter from these "tuffs" and "breccias," and the frequency with which fragments of keratophyre, and even magnetite-keratophyre occur in them. They have been found in the "tuffs" of the Moonbi, Attunga, Manilla, and Bingara districts, and also in the Baldwin Agglomerates. Though, at first sight, the term "intrusive tuff" may seem a contradiction in terms, yet intrusion-breccias are well known, and considerations similar to those explaining the close relation of intrusion and extrusion in suboceanic vulcanicity (see p.124) may assist in the explanation of this apparent anomaly.

Further evidence from the field and laboratory is necessary, before these rocks can be profitably discussed.

Summary and Acknowledgments.—The spilitic series of eruptions in the Nundle district included spilites, dolerites, and keratophyres. So far as can be seen, they are all intrusive into the sediments, and certain spilites intrusive into soft muds, have produced pillowy masses. They are nearly all rich in albite, which appears to be chiefly primary. They do not show at all clearly the evidence for the secondary character of the albite described by Messrs. Flett and Dewey, or that noted by Termier; nor is there evidence that the soda-content of the magma has been segregated in the manner discussed by Daly. Magnetite-keratophyres occur, and their development was brought about by magmatic differentiation assisted by pneumatolysis. Many of their features recall the magnetite-syenite-porphyries of Lappland. An attempt is made to explain their varied structural features by a consideration of magma-viscosity. The formation of ferruginous jasper-veins is described as a post-volcanic process. No complete account can yet be given of the mode of eruption of the rocks, and, in particular, of the manner of formation of the associated breccias.

The writer must gratefully acknowledge the help given by Dr. Flett (Edinburgh), Mr. Harker (Cambridge), and Dr. Nils Sundius (Stockholm). To Professor David, he is indebted for help and counsel, both in the field and in the laboratory, and for all facilities for research in the Geological Department of the University of Sydney.

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APPENDIX.

Addenda and Corrigenda to Parts i., ii., iii.

Owing to the writer's absence from the State, it was impossible for him to see the proofs of the first three Parts of this series, and he regrets that a considerable number of errors appear in the published work. The following corrections should be made :—

Part i.

P.490, line 13 above the base—after "study", read "over wide areas".
P.499, line 9—for "schlueteri", read "schlucteri".
P.504—delete the last sentence.
P.511, line 3—for "peridolites", read "peridotites".
P.516, reference 16—for "opiolischen" read "ophiolitischen".

Part ii.

P.575, line 10—for "lens" read "limestone".
P.576, line 21—for "1000", read "2000".
P.581, line 2—for "they are", read "it is".
P.582, line 33—for "hartzbergite", read "harzburgite".
line 34—for "herzolite", read "therzolite".
P.592, line 5—for "(33). No", read "(33), no),".
P 594, line 13—for "Nundle", read "Woolomin".
Pl. xxii.—The colouring denoting the Woolomin Series has been extended over the zone between the serpentine-line and the eastern limit of the Nundle Series. This zone consists of the rocks of the Bowling Alley Series. A small patch of serpentine has been omitted; it occurs a mile south of Cope's Creek, co-linear with the other masses of serpentine.

Part iii.

P.663, line 10 from base—delete "primary or secondary".
line 2 from base—delete "mineralogical and".
P.664—delete the first footnote.
P.664—in second footnote, for "Mining Museum", read "University Museum".

P.668, line 8—for "(35)", read "(34)".
P.671, line 1—for "bending", read "banding".
P.671, line 29—for "marks", read "makes".
P.672, line 22—for "chrysolite", read "chrysotile".
P.642, line 31—for "bastite", read "magnetite".
P.673, line 31—for "chrysolite", read "chrysotile".
P.675, line 15—after "makes", read "conspicuous".
P.676, line 29—for "3·1", read "5·1".
P.678, line 3—for "chrysolite", read "chrysotile".
P.691, line 7—for "Narsatas", read "Nacatas".
P.692, line 10—for "Narsatas", read "Nacatas".
P.702, line 13—for "sanidine", read "andesine".
P.704—Analyses 2 and 3 have been interchanged. "Spilite, Tregidden" is that commencing with SiO_2 47·56% (to which must be added Fe_7S_8 0·06%). "Spilite, Mullion Island" commences with SiO_2 48·58%). Analysis 4 (M.B.12) CaO and MgO interchanged, read MgO 9·00% CaO 7·46%.

Analysis of pitchstone—for Walkom, read Browne.

P.705—Correct:—

N.T.383—for 100·42, read 101·33.
N.T.280—for 99·99, read 98·69.
M.B.197—for 99·89, read 99·79.
N.T.321—for 101·68, read 101·71.

P.706, N.T.118—for 99·31, read 99·39.
P.706, M.B.36—for 100·81, read 100·89.
P.706, Rodingite, Dun Mt.—delete NiCoO 0·28%.
P.720, line 6—for "fossiferous", read "fossiliferous.".
P.721, line 21—for (p.), read (p.668).
P.722, line 17—for "some", read "come".
P.723, Explanation of Plate xxvii.—Figures 5 and 6 are interchanged.

The following points may be noted, in which some modification or addition is required in the statements made ;—

P.496—The stratigraphical disturbance in the Nundle region is greater than formerly realised, and the details of the succession must be taken with reserve. Particularly is this the case with regard to the breccias.

P.497—The abundance of *flows* of spilite-lava has been disproved in the communication herewith. Recent work shows that the identity of Bowling Alley Point limestone with that of Tamworth and Moore Creek can no longer be maintained. The absence of medium-grained tuff from the Tamworth Series is open to question.

P.500—The conformity of the Baldwin Agglomerates on the Tamworth Series has now been proved.

Pp.576 and 580—See note to p.496.

P.573—Abundant radiolaria have now been found in lenticular limestone beds in the clayshales near Nundle.

Pp.578-9—For reasons given in the paper herewith, the explanation suggested for the mixture of tuff and chert is withdrawn.

P.592—Another small pipe of basalt, about fifty yards in diameter, occurs by Hyde's Creek, at the western side of the alluviated plain.

P.676—The conclusion that serpentine does not increase in density to a noteworthy extent in passing from chrysotile into antigorite is open to question. Professor Becke* and Professor Grubenmann† hold the contrary view. The former gives the specific gravities of chrysotile and antigorite as 2·57 and 2·64 respectively; the latter gives 2·50 and 2·60. Leitmeier's collection of data on this point‡ shows that the evidence is rather incomplete.

P.680. line 25—Near the head of Oakenville Creek at Hanging Rock is a pyroxenite that consists almost entirely of diallage, together with a little hypersthene (1168).

P.696, line 6—To the list of porphyries may be added the following :--

Quartz-mica-porphyrite occurs on the eastern side of Munro's Creek. It is a grey rock, spangled by abundant plates of biotite. Under the microscope (1173), it shows idiomorphic plates of biotite, which is almost uniaxial, and contains abundant inclusions of zircon which are surrounded by dark haloes, also apatite and magnetite. A few phenocrysts of plagioclase and quartz are also developed. The base consists of finely divided plagioclase, with a little quartz and prisms of apatite and minute flakes of biotite. Carbonates occur in abundance. In hand-specimen this rock resembles a minette.

P.698, line 28—Insert :—An odinite dyke(1059) intersects the spilite on the Hanging Rock road. It is remarkable for the frequency with which the augite crystals occurred twinned on the (101) and (122) planes, producing cruciform or star-like aggregates.

P.703—The detailed account of the Tertiary volcanic rocks of the Western Coalfield§ shows their identity with the basalt-theralite teschenite series of rocks which are developed in the Liverpool and Mount Royal Ranges. The list of analyses given is especially worthy of attention.

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† Grubenmann, Die Krystallinen Schiefer, Second Edition, p.55.

‡ Leitmeier, Article on "Serpentin." Handbuch der Mineralchemie, Bd. ii., pp.387-403.

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DESCRIPTION OF PLATES XXV.-XXVII.

Plate xxv.

Fig. 1.—Intersertal Quartz-albite-dolerite(1065); centre of Hanging Rock. (× 20), polarised light.

Fig. 2.—Ophitic and spilitic albite-dolerite(1028); west of Swamp Creek Falls. (× 20).

Fig. 3.—Glomero-porphyritic spilite (155); Woolomin Series, Munro's Creek. (× 12).

Fig. 4.—Spilite with basaltic texture(1029); narrow sill in Moonlight Creek. (× 30).

Fig. 5.—Holocrystalline spilite(1055); central part of pillow, Happy Valley. (× 20).

Fig. 6.—Hypocrystalline spilite(1015); narrow sill(?), Munro's Creek. (× 24).

Plate xxvi.

Fig. 7.—Variolite(1025); margin of a pillow, Swamp Creek. (× 30).

Fig. 8.—Hypohyaline semi-variolite (1039); outer margin of pillow, Swamp Creek. (× 12).

Fig. 9.—Variolite with rod-like structures(1034); Munro's Creek. (× 30).

Fig. 10.—Micro-ellipsoidal spilite(1044); margin of pillow, Happy Valley. (× 30).

Fig. 11.—Keratophyre(541); Hanging Rock. (× 30), polarised light.

Fig. 12.—Magnetite-keratophyre(1075); Hyde's Creek. (× 30).

Plate xxvii.

Fig. 1.—Magnetite-keratophyre(1186); Hyde's Creek. ($\times \frac{2}{3}$).

Fig. 2.—Quartz-keratophyre(1088); Silver Gully, polarised light. (× 50).

Fig. 3.—Nodular magnetite-keratophyre(1096); Hyde's Creek. (× 9).

Fig. 4.—Magnetite-keratophyre(1100); Hyde's Creek. (× 18).